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FEEDBACK IN DYNAMIC DECISION MAKING:
AN EXPERIMENT IN
SOFTWARE PROJECT MANAGEMENT

by

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The objective of this thesis is to use the System Dynamics Model's gaming interface to investigate the effects of feedback on software project managers. Specifically, subjects were provided with either feedforward, outcome feedback, or cognitive feedback to determine which feedback form, if any, improved the subjects' performance when confronted with a complex dynamic task, such as software project management. The results show that subjects in the cognitive feedback condition achieve a higher level of performance than those in either the feedforward or outcome feedback conditions.

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Feedback in Dynamic Decision Making:
An Experiment in Software Project Management

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ABSTRACT

Software project development has been plagued with an infamous reputation for cost overruns, late deliveries, poor reliability and users´ dissatisfaction. Much of this blame has been placed on the manner in which software development projects are managed. The System Dynamics Model of Software Project Management is a quantitative model of software project dynamics that is attempting to gain some valuable insight into the managerial side of developing software systems.

The objective of this thesis is to use the System Dynamics Model´s gaming interface to investigate the effects of feedback on software project managers. Specifically, subjects were provided with either feedforward, outcome feedback, or cognitive feedback to determine which feedback form, if any, improved the subjects´ performance when confronted with a complex dynamic task, such as software project management. The results show that subjects in the cognitive feedback condition achieve a higher level of performance than those in either the feedforward or outcome feedback conditions.

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I. INTRODUCTION

A. BACKGROUND

The proliferation of computing equipment over the past years has served to increase the demand for more reliable and complex software. Unfortunately, the success that has been common to the hardware industry has not been shared by those in the software industry. Today's software projects are typically delivered late and over budget. These inaccuracies have been blamed, in part, on ineffective software project managers. (Schlender, 1989)

A large portion of these inaccuracies associated with the general project management *problem can* be attributed to the difficulty of control. One basic element, evident in any control system, is a means of transmitting feedback information to the control device (Anthony and Dearden, 1980, pp. 3-4). Control relies heavily on information feedback; the question is, however, what kind of feedback?

There has been a great deal of research analyzing the effects of outcome feedback on management control, but this type of feedback has not been effective in improving the performance of decision makers. Research in static situations shows cognitive feedback to be more effective than outcome feedback in enhancing decision quality. However, little work has been done to determine how cognitive feedback may assist management control in complex dynamic tasks.

Researchers have also suggested that the performance of a decision maker in a dynamic decision task, such as software project management, would improve if the decision maker's model matches that of the task. Therefore, providing individuals with feedforward on a task may improve decision quality as opposed to outcome feedback. The focus of this thesis is on studying the effects of outcome feedback, cognitive feedback, and feedforward on one particular management control problem, that of software project management.

B. EXPERIMENTATION TOOL

The System Dynamics Model of Software Project Management (SDM) is a comprehensive model of the software development process that integrates both the managerial and software development activities. Through the use of a model,

> The effects of different assumptions and environmental factors can be tested. In the model system, unlike the real systems, the effect of changing one factor can be observed while all other factors are held unchanged. Such experimentation will yield new insights into the characteristics of the system that the model represents. By using a model of a complex system, more can be learned about internal interactions than would ever be possible through manipulation of the real system. Internally, the model provides complete control of the system's organizational structure, its policies, and its sensitivities to various events. (Forrester, 1961, p.1)

Additionally, this particular model provides an effective means of studying dynamic decisions.

The gaming interface of the System Dynamics Model provides experimenters with the ability to analyze the efforts of any number of software project managers. The experimenter can vary the type of feedback given to the manager by specifically tailoring the model's interface for that particular manager. The model provides the capability of displaying a wide variety of variables in either tabular or graphical form. The results of each manager's run can then be collected and analyzed to determine any particular trends in their decision making process.

C. RESEARCH QUESTION

Recent laboratory experiments have provided valuable insight into human behavior in a variety of decision-theoretic contexts. This research, however, has focused mainly on static and discrete judgements. As Hogarth (1981) emphasizes

> ...the continuous, adaptive nature of the judgmental processes used to cope with a complex, changing environment.... With few exceptions...judgment researchers have focused on discrete incidents (particular actions, predictions, and choices) that punctuate these continuous processes; furthermore, task environments are typically conceptualized to be stable. (p. 198)

Sterman (1989a) argues that experimental studies of the "continuous, adaptive nature of judgmental processes" in a dynamic system, such as software project management, can be conducted in the laboratory with the aid of computer simulation models. He adds that "simulations can represent the structure and complexity of such systems with great fidelity and permit controlled manipulations of the decision context and information presented to the subject."

As an example, the research question addressed in this thesis is: What effects do cognitive feedback, outcome feedback, and feedforward have on decision makers in a dynamic decision environment such as software project management?

D. CONTRIBUTION

Enhancement of management control through the use of cognitive feedback has attracted much attention (Kleinmuntz, 1985; Sterman, 1989a). The use of cognitive feedback to aid software project managers has not, however, been investigated. The goal of this research, therefore, is to establish the importance of cognitive feedback as an aid to the decision making process of software project managers.

II. THEORETICAL PREMISE

A. FEEDBACK IN A DYNAMIC DECISION ENVIRONMENT

1. Static vs Dynamic Decision Environments

When analyzing human judgmental ability, it is important to distinguish between static and dynamic decision environments. Although much of human decision making is composed of discrete incidents (particular actions, predictions, and choices) occurring in a seemingly static environment, these incidents are only a subset of, and serve to punctuate, our continuous processes which occur in response to our dynamic environment. As Hogarth (1981) indicates, the limitation of existing research on human judgment is that it focuses only on these discrete incidents in static environments. Since most decisions are made in a continuous, dynamic environment, it is argued that biases observed during these discrete incidents occur as a result of heuristics that are derived from man's more natural continuous environment. According to Hogarth (1981), failure to evaluate human judgement as a continuous process has two distinct pitfalls:

> First, insufficient attention has been paid to the effects of feedback between organism and environment. Second, although judgmental performance has been evaluated according to the principles of optimal behavior implied by decision theory and the probability calculus, few researchers have questioned whether the assumptions of such models apply to continuous processes. (p. 198)

Studies involving human decision making cannot overlook the importance of feedback. Most all human judgement is used to facilitate an action and this action is most often followed by immediate feedback. Our next action is then directly influenced by this feedback causing a action, outcome, feedback, action loop. Hogarth (1981) indicates that the tendency to overlook feedback as a crucial part of this loop comes as a result of its "ubiquity" in the environment. As Powers states (1973):

> All behavior involves strong feedback effects, whether one is considering spinal reflexes or self-actualization. Feedback is such an all-pervasive and fundamental aspect of behavior that it is as invisible as the air we breathe. Quite literally it is behavior--we know nothing of our own behavior but the feedback effects of our own outputs. (p. 351)

2. Inadequacy of Outcome Feedback

A majority of the work that has been done in relation to the dynamic decision environment has examined the effects of outcome feedback on the decision making process (Brehmer, 1987; Sterman, 1989b). Evidence, however, indicates that presenting outcome feedback in a dynamic environment has dysfunctional effects that persist over time. These effects fall into four categories.

First, subjects typically misperceive time lags in the system which confronts them. In Sterman's (1989b) stock management problem, subjects fail to adequately account for the supply line. Subjects confronted with Brehmer's (1987)

DESSY experiment show improvement after spending two hours a day for four days with the system, "but only if there are no delays in the system. If there are even minimal delays, the subjects´ control over the system does not improve." As Brehmer states, "this [fact] is somewhat disconcerting, since delays are probably a more common case than that of immediate feedback."

The second dysfunctional effect that typically plagues subjects in outcome feedback experiments is a wide oscillation of results over time (Sterman, 1989b). In Sterman´s stock management problem, this oscillation is seen in the inventory level. Subjects in Sterman´s experiment also attribute the dynamics of the system to external variables rather than as a direct result of their interactions with the environment. Thus, subjects misperceive the feedback from their own decisions. The final dysfunctional effect of outcome feedback is seen in (Wagenaar, 1985) where subjects misperceived exponential growth over time (and hence, nonlinear changes).

Experimental evidence indicates that outcome feedback is not an adequate aid in decision making. As Sterman (1989b) states: "The results here suggest that outcome feedback alone is not sufficient: by attributing the source of change to external factors, people´s mental models lead them away from the true source of difficulty." Kleinmuntz and Thomas (1987) drew similar conclusions: "Despite the corrective benefits of outcome feedback..., it may still be quite difficult to learn how to improve one's decision rules using outcome feedback alone." The inadequacy of outcome feedback in dynamic environments has led researchers to explore alternative means of improving performance.

B. ALTERNATIVES TO OUTCOME FEEDBACK

1. Cognitive Feedback

In contrast to outcome feedback, which provide subjects with information about the accuracy or correctness of their response, *cognitive feedback* represents "information regarding the how or why that underlies this accuracy." (Jacoby et al., 1984) Doherty and Balzer (1988) describe cognitive feedback as information which provides subjects with the following relationships:

1. Between cues and criterion, i.e., information about the task. This is known as task information and it is characterized by three kinds of relational indices--overall task predictability (Re), cue intercorrelations (rij), and correlations between cues and the criterion (rie).
2. Between cues and the person's inferences, i.e. information about the person's cognitive state. This is known as cognitive information and, in terms of the lens model, largely mirrors task information (the only exception being cue intercorrelations which is not represented in this relationship).
3. Between cognitions and the distal objects. This third category comprises indices of "functional validity" information, or, information about the relation of the cognitive system to the task system (Balzer et al., 1989). These indices include the achievement correlation (ra), the matching index (G), and the correlation between the residuals from the predictions of those models (C).

Since Cognitive Feedback has been used largely for static tasks in the context of the lens model, the aim of this study is to extend this notion to a dynamic decision situation using a system dynamics model. As Sterman's (1989b) research indicates "the efficacy and robustness of decision strategies lies not only in the availability of outcome feedback, but depends crucially on the nature of the action feedback between decisions and changes in the environment which condition future decisions." Brehmer (1987) concludes from his DESSY experiment that, "results on verbalization suggest that information about the system may need to be communicated in nonverbal form, and that various graphic displays may prove useful." Additionally, Kleinmuntz and Thomas (1987) state that "feedback about the decision process being used may also be valuable...." Each of these statements support the belief that cognitive feedback should prove more beneficial than outcome feedback when presented to subjects confronted with a dynamic decision situation.

2. **Feedforward**

Another method of assisting subjects in forming mental models of complex systems is through feedforward. Feedforward can be defined as "the transmission of task information directly to the subject." (Bjorkman, 1972) Studies by Conant and Ashby (1970) showed that in order to perform effectively with a dynamic process, an operator must have a model of the system. Bjorkman (1972) provides three hypotheses with regard to the use of feedforward in knowledge and policy formation:

1. Knowledge acquired by feedforward should be more accurate and consistent since it does not suffer from various sources of error and bias due to the trial--by--trial accumulation of information.

2. Feedforward relieves the learner from a certain amount of cognitive strain since he already knows things which otherwise should have been learned by feedback. This may give the learner an increased opportunity to focus on policy formation.

3. It seems reasonable to assume that feedfor rd favors an analytical rather than intuitive mode of thought. Uncertainty, which is one of the factors that contributes to intuitive rather than logical, stepwise inference, has been removed entirely or partly by feedforward.

The operationalization of feedforward occurred, for the purposes of this study, through the use of a special training session which assisted subjects in forming a model of the software project management system.

3. Cognitive Feedback vs Feedforward

Although feedforward assists subjects in forming a mental model of the system, task information is presented only prior to performing the task (or, at best, the information is presented prior to performing the task and the same information is available to the subject throughout the task). As shown by Morris and Rouse (1986), "a priori knowledge can be a powerful basis for gaining new knowledge or, if incorrect, an impediment to gaining correct knowledge." A distinct advantage gained through cognitive feedback is that subjects are constantly being presented with task information so that they may change their mental models of the system to meet changes experienced in the environment.

C. HYPOTHESES

Two primary hypotheses guide the research question. The first hypothesis is concerned with the relationship between feedback condition and subject performance. As indicated in sections 1 and 2, cognitive feedback and feedforward assist subjects in forming a mental model of the task. Thus, subjects receiving this information should perform better than those not receiving this information. Additionally, cognitive feedback continually assists subjects in keeping their mental model current with the dynamic environment. One would therefore expect subjects receiving cognitive feedback to also outperform those subjects receiving feedforward. This leads us to the first hypothesis:

> **Subjects receiving cognitive feedback will perform better than subjects receiving either outcome feedback or feedforward.**

The second primary hypothesis addresses the characteristic of the task which confronts the subject. This is accomplished by measuring each subjects performance during each of three software projects with varying degrees of complexity (details on the three projects, referred to as ideal, fixedsize/bad estimates, and undersize will be provided in Chapter III). We would expect that subjects would perform better when confronted with a task with less complexity. Since the ideal project has fewer lags and less of the "noise" associated with more complex tasks, it is regarded as the least complex of the three projects. The second hypothesis is therefore:

> **Subjects performance while managing the ideal software project will be better than when managing either the fixedsize/bad estimates or undersize software projects.**

III. METHOD

A. TASK ENVIRONMENT

The task that subjects were asked to perform was in many ways similar to flight simulators that pilots use to mimic flying an aircraft from takeoff at point A to landing at point B. Instead of flying an aircraft, though, the simulation mimicked the life of three real software projects from the start of the design phase until the end of testing. Subjects were more than outside observers, however, they performed an actual role in the project: that of the project manager.

Specifically, subjects were required to track each project's progress using a number of reports generated by the project team at different intervals throughout the project life. They then made project staffing decisions based on the knowledge gained from those reports. As project manager, subjects were permitted to hire additional staff or decrease the staffing level as deemed necessary to complete the project. Their objective in setting the staffing level was to decide on the best compromise between finishing on an acceptable schedule while avoiding an excessive cost overrun. Specifically, subjects attempted to:

1. complete the project on schedule,
2. at the lowest possible cost, and

3. in any case, complete it before the maximum tolerable completion date.

Unlike Sterman's (1989b) use of a Generic Stock-Management System and Brehmer's (1987) DESSY experiments which presented subjects with open-ended tasks, the task which confronted each subject in our experiment was close-ended with each project having a finite completion point.

The task of managing a Software Project was selected for several reasons. First, Software Project Management has all of the characteristics of a dynamic problem (Brehmer and Allard, 1985):

1. It requires a series of decisions.
2. The environment changes both spontaneously (staff productivity, changing requirements, etc) and, as a consequence of the decision maker's actions.
3. The time element is critical; it is not enough to make the correct decisions and to make them in the correct order, they also have to be made at the correct moment in time.

Like Brehmer's (1987) DESSY experiment, the Software Project Management problem is interesting

> ...because the standard normative theories for decision making do not apply (Brehmer and Allard, 1985); the models of the task embodied in these theories simply do not fit this kind of task. It is not possible to compute the correct course of action. This can only be found from a model of the system and, before the operators have developed such models, they will not be able to control the system. The research problem, is whether or not people are able to develop good mental models of this and similar tasks. (p. 24)

Finally, Software Project Management is currently a critical issue due to the frequency of projects that are delivered over budget and late (Schlender, 1989).

Three separate projects, referred to as ideal, fixedsize/bad estimates, and undersize, were selected in an attempt to cover the spectrum of projects that typically confront Software Project Managers. Table 1 shows the characteristics associated with each of the three projects.

TABLE 1. PROJECT CHARACTERISTICS

	Ideal	Undersize	Fixedsize
Project cost: initial estimate (Man-days)	3,721	1,460	2,972
Project Size: initial estimate (No. of tasks)	1,067	397	1,866
Actual Size of Project (No. of tasks)	1,067	610	1,866
Project duration: initial estimate (Days)	413	362	380
Maximum tolerable project duration (Days)	479	420	441

Notes: 1. The ideal project had accurate initial estimates of project size and cost.
2. The undersize project had understated initial estimates of size, and therefore, cost.
3. The fixedsize project had an accurate initial estimate of size. The initial cost estimate was, however, understated.

Subjects were presented with accurate initial estimates as well as accurate information throughout the entire lifecycle of the ideal project. Subjects were given accurate initial estimates for the fixedsize/bad estimate project, however, estimates given during the project lifecycle were typically unreliable. The undersize project was a project that grew in size from an initial estimate of 397 tasks to 610 tasks at project completion. This growth in project size was attributable to changing user requirements.

B. MODEL

The Model of Software Project Management attempts to provide "a comprehensive model of the dynamics of software development that enhances our understanding of, provides insight into, and makes predictions about the process by which software development is managed." (Abdel-Hamid and Madnick, 1989) Figure 1 shows the model with its four subsystems: the human resource management subsystem, the software production subsystem, the controlling subsystem, and the planning subsystem. "The model was developed on the basis of a battery of 27 field interviews of software project managers in five software producing organizations, supplemented by an extensive database of empirical findings from literature." (Abdel-Hamid, 1989) The human resource management subsystem accounts for variables related to the workforce, namely, the hiring rate, training, and turnover of project personnel. The software production subsystem models the designing, coding, and testing phases of the software development lifecycle. This subsystem also accounts for the quality assurance effort required for project develop as well as the actual productivity of the project team. In contrast to actual productivity, perceived productivity is described in the control subsystem. Perceived productivity directly influences a manager's estimate of

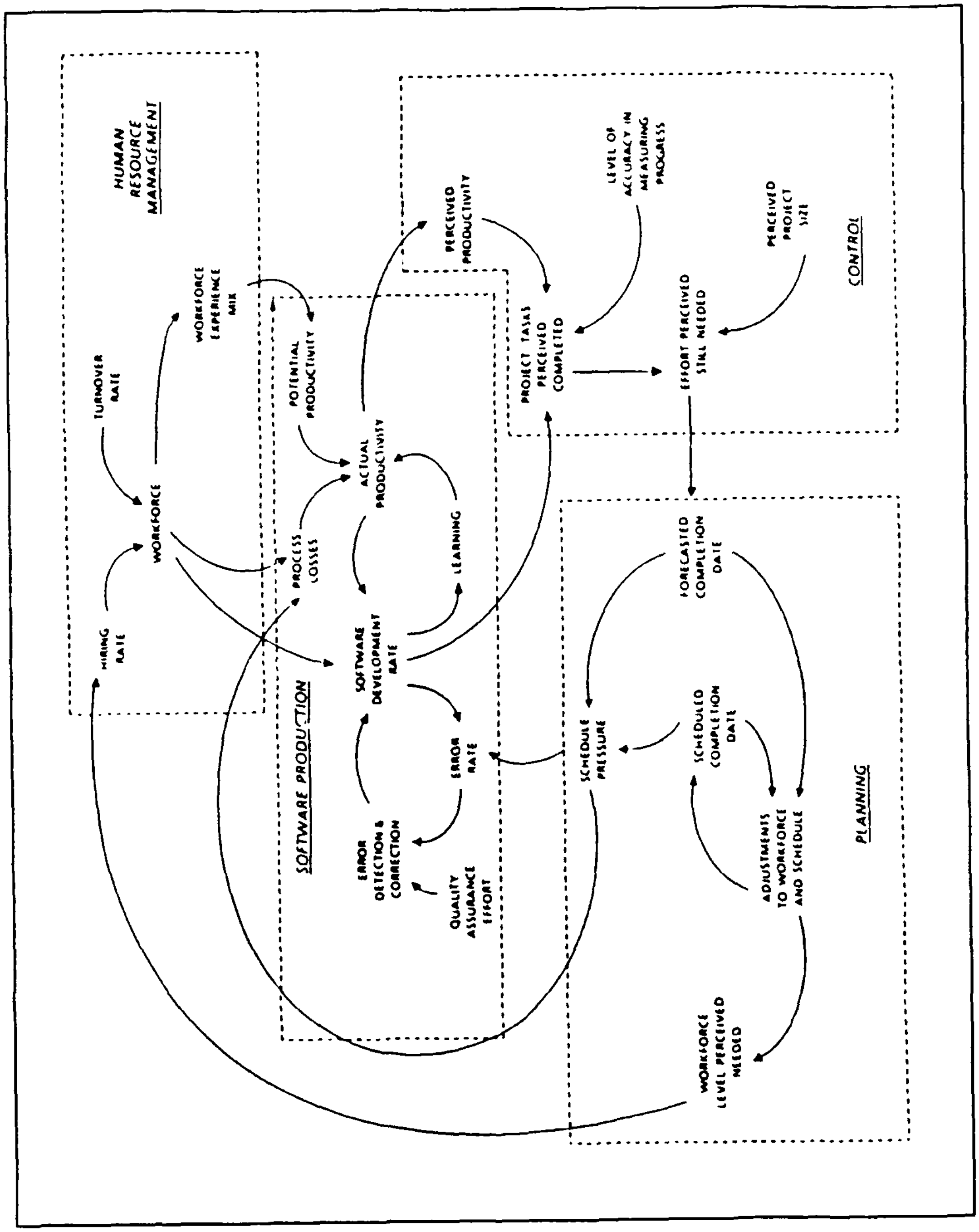

Figure 1. Model Structure

project tasks perceived to be completed. This estimate, however, is often unrealistic with regard to software development since one must have accurate knowledge of rates of accomplishment and resources expended to date (Abdel-Hamid and Madnick, 1989). Thus, this variable often is no more than a measurement of budgeted resources that have been expended. The planning subsystem, the final subsystem of the model, provides initial project estimates such as project cost, schedule, and staffing. As the project continues through its lifecycle, these estimates will change to reflect management's decisions.

C. EXPERIMENTAL DESIGN

The research design is illustrated in Table 2. The experiment used a factorial design with two components in order to capture the feedback condition and the project type. These components are between-subjects and within-subjects.

TABLE 2. EXPERIMENTAL DESIGN

	Type of information								
	Cognitive Feedback Project No.			Outcome Feedback Project No.			Feedforward Project No.		
Order	1	2	3	1	2	3	1	2	3
Order 1	I	U	F	I	U	F	I	U	F
Order 2	U	I	F	U	I	F	U	I	F
Order 3	F	U	I	F	U	I	F	U	I

Notes: 1. Participants were randomly assigned to one of the feedback conditions and one of the sequences of task conditions.
2. I, U, and F refer to ideal, undersize, and fixedsize projects, respectively.

1. **Between-Subjects**

The fundamental objective driving the experiment is to determine the effect of cognitive feedback, i.e., determine how best the operator can be conveyed a model of the system over time (Brehmer, 1987): through feedforward, outcome feedback, or cognitive feedback. This is the rationale for the between-subject component.

2. **Within-Subjects**

In addition to determining if systematic differences exist among experimental conditions, feedback studies also seek to study the effect within each condition over time. This is referred to as within-subject design (Barlow and Hersen, 1984, p. 66) and involves multiple measurements over different points in time. In this experiment, the within subjects aspect was operationalized by using three separate projects, namely, the ideal, fixedsize/bad estimate, and undersize projects.

Randomization between and within subjects was achieved using a Latin Square Design as follows (Kirk, 1982, pp. 311-312):

First, each project was assigned a corresponding letter.

A: Ideal Project(IL)
B: Fixedsize/bad estimate Project(FB)
C: Undersize Project(UN)

Next, two sequences of random numbers were generated.

(2,1,3) (3,1,2)

The appropriate square is then selected.

A	B	C
B	C	A
C	A	B

Rows are then ordered according to the first set of random numbers.

B	C	A
A	B	C
C	A	B

Next, columns are ordered according to the second set of random numbers.

A	B	C
C	A	B
B	C	A

Finally, the notation is converted according to project name.

	G1	G2	G3
	IL	FB	UN
Task	UN	IL	FB
Order	FB	UN	IL

Therefore, Group 1 receives the projects in the order: ideal, undersize, and fixedsize/bad estimate.

D. SUBJECTS

The experiment was conducted using 56 graduate students. Participants were divided into nine groups based on the feedback condition and task order. Table 3 shows the feedback condition and task order provided to each group.

Each subject was assigned a number from 1 to 56 according to the alphabetical order of his last name. Two digit random numbers were then generated using a random number table.

TABLE 3. GROUP ASSIGNMENTS

GROUP NUMBER	FEEDBACK CONDITION/TASK ORDER
1-1	Cognitive Feedback, G1 Task Order
1-2	Cognitive Feedback, G2 Task Order
1-3	Cognitive Feedback, G3 Task Order
2-1	Outcome Feedback, G1 Task Order
2-2	Outcome Feedback, G2 Task Order
2-3	Outcome Feedback, G3 Task Order
3-1	Feedforward, G1 Task Order
3-2	Feedforward, G2 Task Order
3-3	Feedforward, G3 Task Order

Subjects corresponding to the first six numbers were assigned to group 1-1, the next six in group 1-2, etc. Duplicates and random numbers greater than 56 were disregarded. Due to the number of subjects not being evenly divisible by nine, groups 1-3 and 2-3 had seven subjects each.

1. Participant Profiles

Two types of subject characteristics could potentially have affected results in this experiment: demographic factors and task-specific factors. Demographic factors were operationalized as age, full time work experience, years since completion of undergraduate education, familiarity in working with computers and hours per week a subject spent working on computers. Table 4 profiles the subjects with respect to demographic factors. The task-specific factor was operationalized by asking subjects whether they had any prior experience in the task. It was determined that none of the subjects had any significant experience in software project management.

TABLE 4. PARTICIPANT PROFILES. (Means).

By feedback condition:

	Cognitive Feedback	Outcome Feedback	Feedforward
AGE	34	33	31
WK_EXP	14	13	10
Y_UGRAD	10	10	8
FAM_COMP	5	6	5
HRS_COMP	10	9	9

By project order:

	Order 1	Order 2	Order 3
AGE	34	30	34
WK_EXP	14	10	13
Y_UGRAD	10	8	11
FAM_COMP	6	5	5
HRS_COMP	12	8	9

Key: AGE = Age of subjects (Years)
WK_EXP = Full time work experience (Years)
Y_UGRAD = Years since completion of undergraduate education
FAM_COMP = Familiarity of subjects with computers (1 = not familiar, 9 = very familiar)
HRS_COMP = Hours per week spent using computers

E. INFORMATION PROVIDED TO SUBJECTS

Subjects were provided different types of information based upon the feedback condition corresponding to their group. During the lifecycle of each project, the experiment software would pause at 40 day intervals to allow subjects to review this information.

1. Outcome Feedback

Subjects receiving outcome feedback were given only one report, the Project Status Report, at the end of each interval. Information provided in this report is shown in Table 5.

TABLE 5. PROJECT STATUS REPORT

CURRENT INTERVAL STATISTICS: Elapsed Time =	80	Days
INITIAL ESTIMATES: (These will not change throughout the project)		
Project size	1,067	Tasks
Project duration	413	Days
REPORTED STATISTICS at Time = = = = =>	80	Days
% Development Reported to be complete	10.26	Percent
% Testing Reported to be complete	0.00	Percent
Perceived Total Project Size at this point	1,066.67	Tasks
Perceived Total Project Cost at this point	3,721.00	Man Days
Total Number - Fulltime Equivalent Staff	4.3	Fulltime staff
New Estimate of Project Duration (start - end)	829	Days
Maximum Tolerable Completion Date	479	Days
Total Man Days Expended	348.36	Man Days
Total Number of Tasks developed to date	137.45	Tasks

PRESS <ENTER> TO RETURN TO MENU

2. Feedforward

In addition to receiving the Project Status Report (Table 5), subjects in the feedforward groups were given a separate training lecture prior to the experiment which provided further insight into the human resource management subsystem of the Model of Software Project Management. Figure 2 is an exploded view of this subsystem.

The first part of the feedforward training provided subjects with instruction on two concepts critical in the human resource management subsystem: average productivity and net cumulative contribution. To demonstrate the importance of carefully considering each of the two concepts, the following human resource management problem was given:

The initial project team consists of five people each with a productivity of ten lines of code (LOC) per man day (MD) thus giving a total output of 50 LOC per day for the entire team. The assumption is that the project is behind

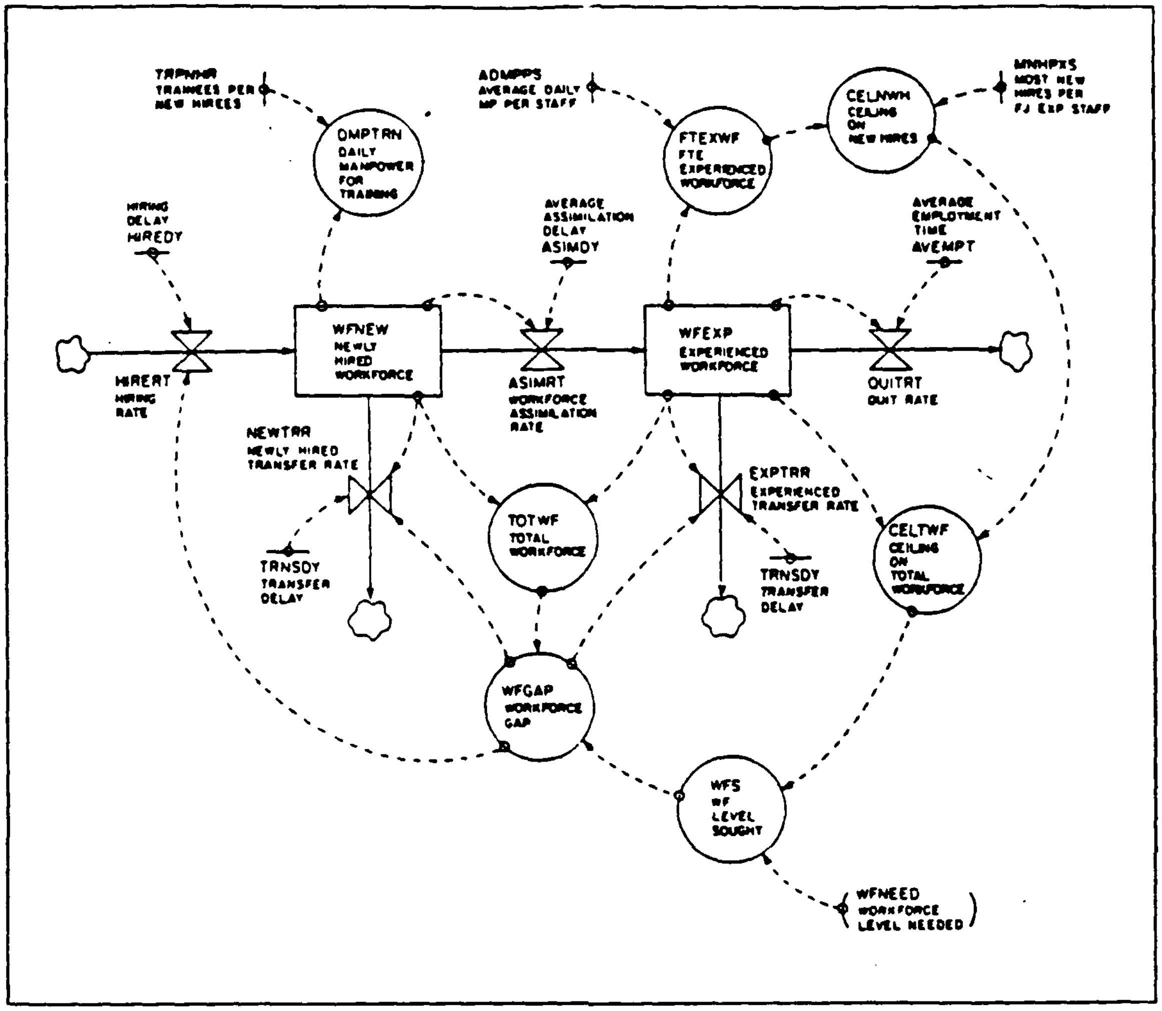

Figure 2. Human Resource Management Subsystem

schedule and the manager must make a decision either to add a new person to the team or accept the schedule slippage.

Case one examines the effect of adding a new person with a productivity of 8 LOC per man day. If this person is added, it is expected that the productivity of the old team will decrease by 10 percent (i.e., 9 LOC/MD) due to training and the added communication overhead. Case two also adds a new person but this person's productivity is only 4 LOC per man day. Again, this will cause a 10 percent decrease in the productivity of the old team.

In the first case the output of the team increases to 53 LOC/Day (given by 5 team members x 9 LOC/MD + 8 LOC/MD for the new member). The average productivity of the team is now 8.8 LOC (53 divided by 6 team members). The net cumulative contribution of the new person is 53-50 or 3 LOC/MD. Since the average productivity of the team decreases, the cost of the project will increase, but since the net cumulative contribution of the new person is positive, the schedule will go down.

In case two, the output of the team is only 49 LOC/Day (5 team members x 9 LOC/MD + 4 LOC/MD for the new team member). The average productivity of the team is 8.1 LOC (49 divided by 6 team members), and the net cumulative contribution of the new person is 49-50 or -1 LOC/MD! Thus the addition of the new team member is detrimental to the project, not only driving up the project's cost but its schedule as well.

Although the mathematics of the concepts are relatively simple, the importance of the lesson is to realize that adding a person (or people) to a late project will not always improve the project's schedule. The manager must look closely at the average productivity of the project team as well as the net cumulative contribution of any team members added.

The second part of the feedforward training lecture focused on considerations involved in the willingness to change workforce (WCWF). Subjects were presented with the equation,

$$\text{Workforce Sought} = \text{Indicated Workforce} * \text{WCWF} + \text{Current Workforce} * (1-\text{WCWF})$$

and its relation to the WCWF curve (Figure 3).[1] The instructor explained to subjects that a manager at a point in the project which yields a WCWF value of zero from the curve is, in essence, not willing to change his workforce and thus, the workforce sought will be equal to the current workforce. If, however the manager is at a point in the project where the WCWF is one, the manager is very willing to change the workforce and thus, the workforce sought is equal to the indicated workforce.[2]

3. **Cognitive Feedback**

Subjects receiving cognitive feedback also received the Project Status Report (Table 5) after each 40 day interval. Additionally, personnel receiving cognitive feedback had the option to view a Cognitive Feedback Report as well as four plots. The Cognitive Feedback Report (Table 6)

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[1] Subjects were told that the time parameter referred to in the figure was the sum of two parameters from SDM's human resource management subsystem. These two parameters are the hiring delay, set at 30 days for this experiment, and the assimilation or training time, set at 20 days.

[2] The indicated workforce is synonymous with the workforce necessary to stay on schedule.

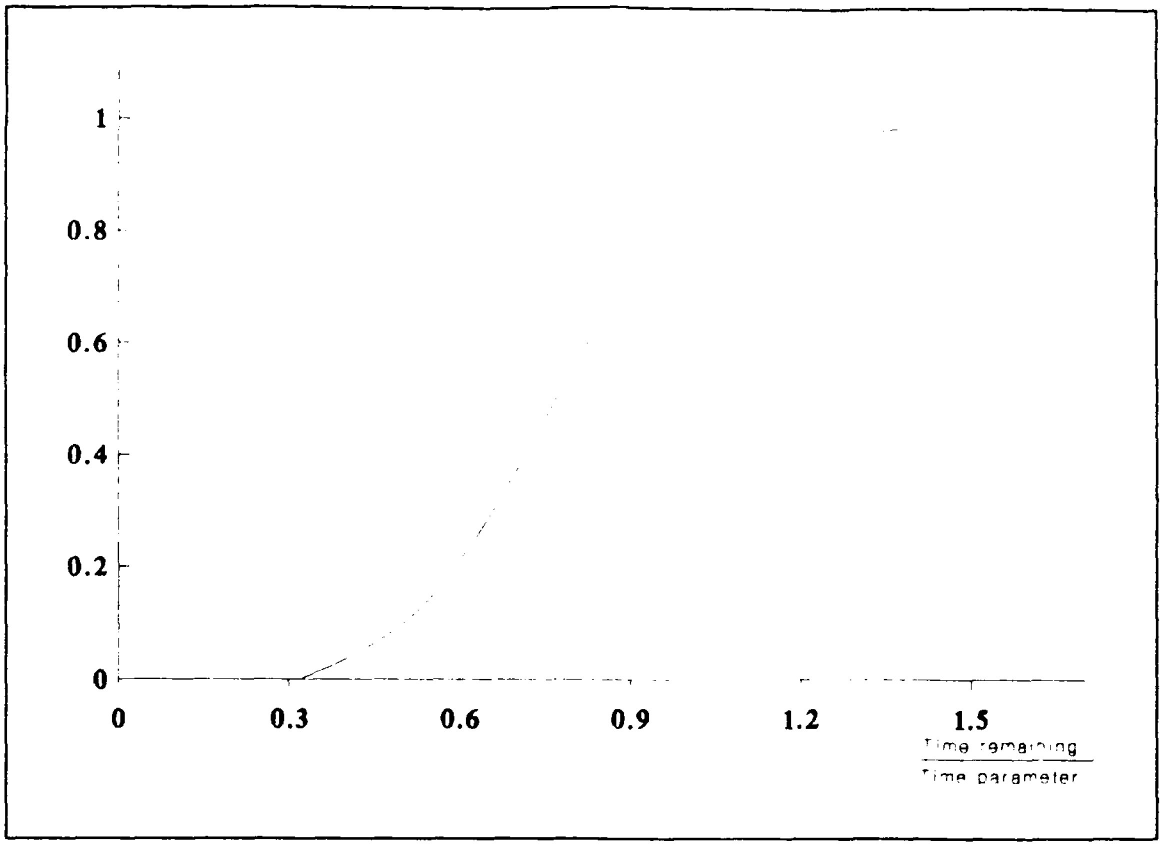

Figure 3. WCWF Curve

TABLE 6. COGNITIVE FEEDBACK REPORT

CURRENT INTERVAL STATISTICS: Elapsed Time =	80	Days
INITIAL ESTIMATES: (These will not change throughout the project)		
Project Size	1,067	Tasks
Project Duration	413	Days
REPORTED STATISTICS at Time = = = = = = =>	80	Days
Fraction of Workforce that is Experienced	0.9	
Perceived Average Productivity	0.4	Tasks/Man-day
Communication Overhead	0.01	
Total Number - Fulltime Equivalent Staff	4.3	Fulltime Staff
Estimated Workforce Needed to Stay on Schedule	4.5	Fulltime Staff
PRESS <ENTER> TO RETURN TO MENU		

provided information on specific workforce variables. Four plots, described as the Project Size Plot, the Staffing and Schedule Plot, the Workforce Mix Plot, and the Workforce

Productivity Plot, were provided to assist subjects in spotting trends developing throughout the project lifecycle.

The plot on Project Size (Figure 4) plotted two variables, the perceived total project size to date (PJBSZ) and the perceived total project cost to date (JBSZMD), over the project lifecycle. This plot provided subjects information on whether any schedule or budget slippage was a result of either unexpected increases in the project's size (e.g., due to changes in users' requirements), or that the effort required to complete the project was initially

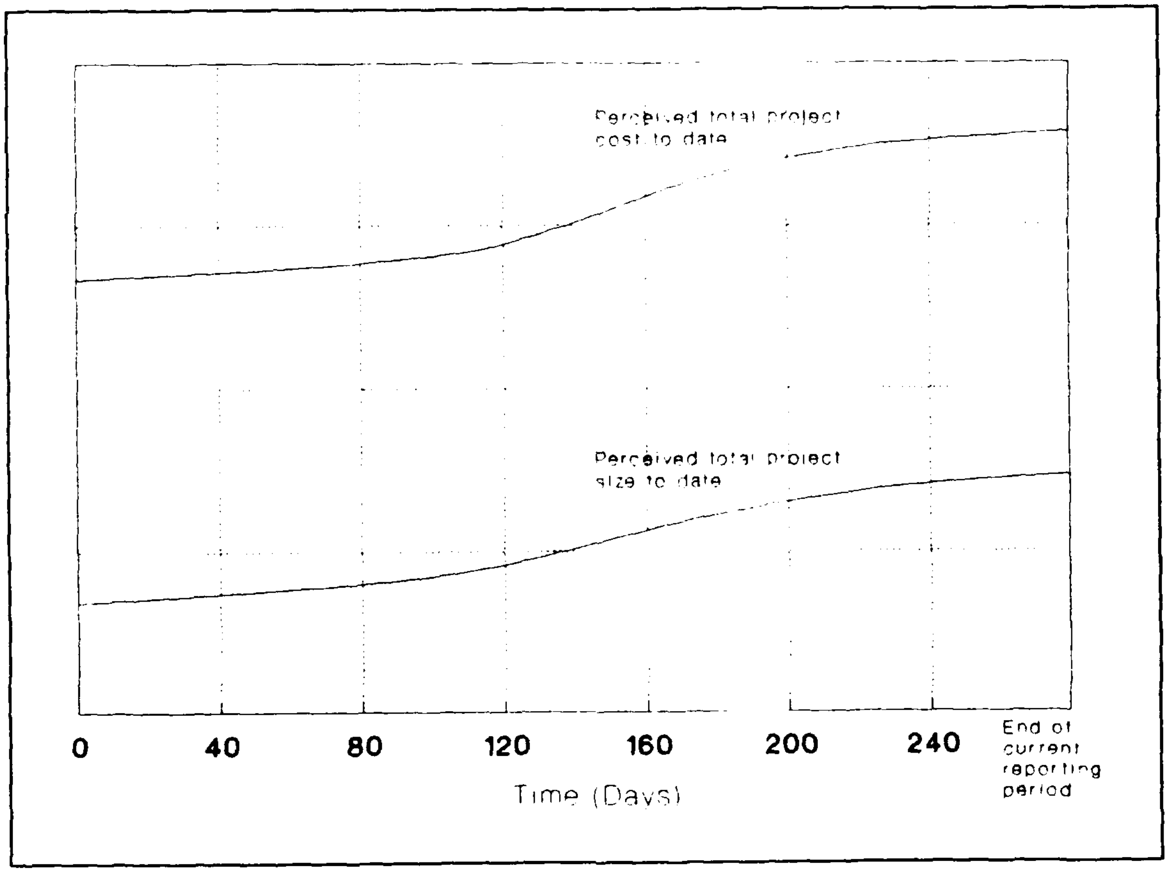

Figure 4. Project Size Plot

underestimated (e g., because the project complexity was underestimated). If the former case were true, subjects would expect to see the variable PJBSZ increase over time. If the latter were true, then the variable JBSZMD would increase over time.

The plot on Project Staffing and Schedule (Figure 5) plotted three variables of the project lifecycle: the total number of fulltime equivalent staff (FTEQWF), the new estimate of project duration from start to end (SCHCDT), and

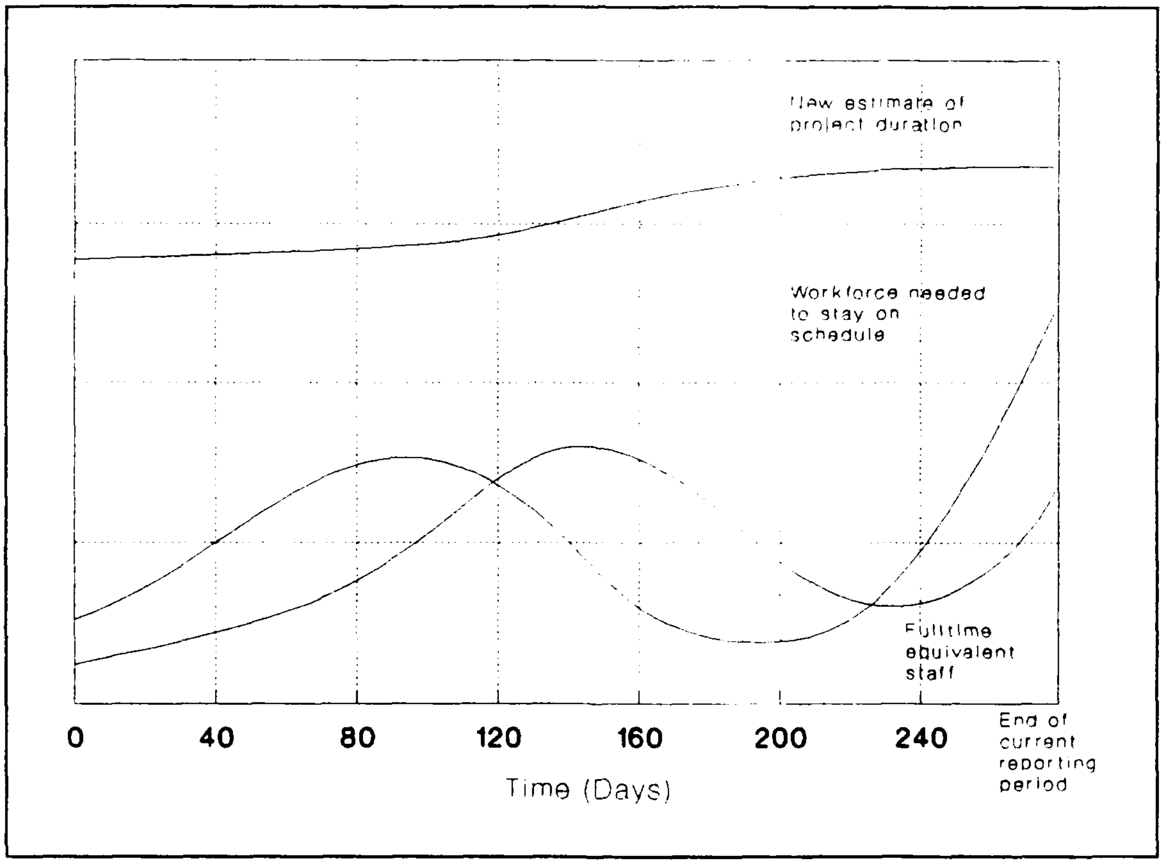

Figure 5. Project Staffing and Schedule Plot

the estimated workforce needed to stay on schedule (WFINDC). This plot provided feedback on the trade-off between minimizing schedule over-runs versus minimizing cost over-runs. When a project runs into difficulties, a manager can choose to stick with the project's schedule (SCHCDT) by increasing the workforce level (FTEQWF). This practice always increases the cost of a project. On the other hand, a manager might wish to minimize his/her cost over-run, by avoiding an increase in the workforce level, and instead, opt to increase the project's scheduled completion date. The indicated workforce level (WFINDC) is provided as an estimate of the workforce needed to stay on schedule.

The plot on Workforce Mix (Figure 6) provided subjects with feedback on their staffing decisions. In general, staffing decisions have the greatest impact on productivity. This option plotted three variables: the total number of fulltime equivalent staff (FTEQWF), the fraction of the workforce that is experienced (FRWFEX), and the planned workforce (PLANWF) over the project lifecycle. This plot was deemed useful for two reasons. First, larger workforces will, in most cases, be less productive because of the increases in communication and training overheads. Second, the workforce mix (i.e., percent of experienced vs new staff in the workforce) will also have an impact on productivity. The larger the percentage of experienced people in the workforce, the more productive the workforce.

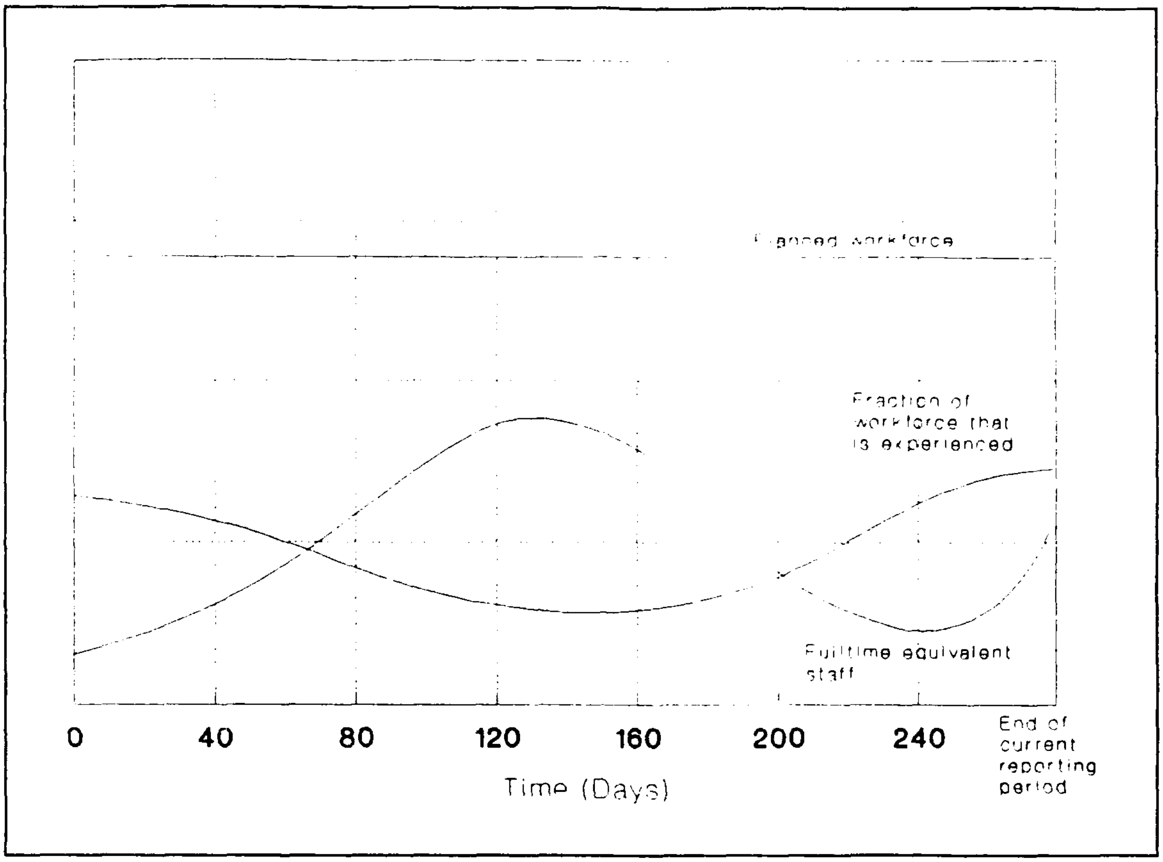

Figure 6. Workforce Mix Plot

The plot on Workforce Productivity (Figure 7) provided subjects with information on the average productivity of their team. It displayed the relationship between the total number of fulltime equivalent staff (FTEQWF), the perceived average productivity of the workforce (ASSPRD), and the communication overhead associated with the workforce (COMMOH) throughout the project lifecycle. The basis for presenting this plot was, again, twofold. First, the larger the workforce, the lower the average productivity. This is due to the time people "waste" in communicating with teammates. Second, the communication overhead curve shows subjects exactly what percentage of a person's time is wasted in communication with others.

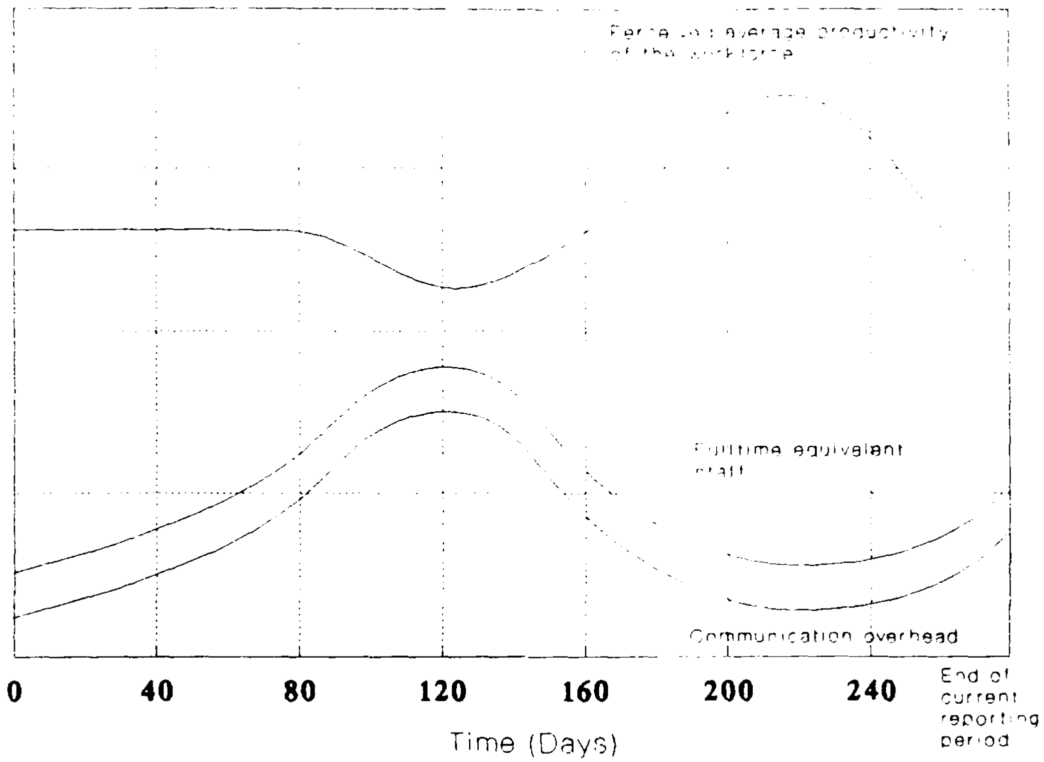

Figure 7. Workforce Productivity Plot

F. EXPERIMENTAL SETTING

The experiment was conducted in two computer labs with two attendants per lab. Each subject was assigned a specific terminal and was given documentation (see Appendix) and a disk according to his/her group assignment. Subjects were given time to read over the documentation and ask questions about the conduct of the experiment. Questions pertaining to the task were not permitted. After reading the documentation, subjects ran several intervals of a "dummy" project to familiarize them with the reports, plots and keystrokes required to traverse through the screens they were presented with. Attendants assisted the subjects with any technical difficulties. After completing the trial run, subjects were permitted to proceed with each of the three projects at their own pace.

G. DEPENDENT MEASURES

Two dependent variables, deviation from initial estimates and staff productivity, were used to analyze the performance of each subject. Two numbers were used to determine the deviation from initial estimates. The first number was the difference between the subject's completion time and the estimated completion time. The second number was the difference between the subject's final cost and the estimated project cost. These numbers were then averaged to yield the deviation (overrun or underrun) from the initial project estimates. Project time is defined as the length, measured in days, required for the subject to successfully manage each project from start to end. Project cost measures the resources expended, in man days, to complete each project. The staff productivity is defined as tasks per man-day and was determined by dividing the number of tasks associated with each project by the total cost of that project when managed by a particular subject.

Lower benchmarks for time and cost were determined for each of the three projects by running 15 simulations for each project using random staff sizes. Minimum and maximum staff sizes for each project type were determined from subjects' decisions. Five hundred random numbers were then generated for each project to fall within the minimum and maximum staff size. The 15 simulations were then run for each project using staff sizes taken sequentially from the 500 generated in that project's staff range.

H. EXPERIMENTAL RESULTS

Tables 7 through 11 summarize the results of the experiment. Cases in which subjects made significant errors were discarded, and data from 45 subjects was retained for analysis. Table 7 shows performance between subjects, as well as within subjects, with respect to deviations from the initial project estimates.

Applying the approach suggested by Winer (1971, p. 697), the following analysis of variance (ANOVA) model suited for multiple Latin Squares was used to test Hypotheses:

$$Y_{ijk(l)m} = \mu + \alpha_i + \beta_j + \gamma_k + \chi_l + \delta_m + (\gamma\chi)_{kl} + (\gamma\alpha)_{ki} + (\gamma\beta)_{kj} + e_{ijk(l)m} \text{ where:}$$

μ is constant,

α_i is the sequence of the projects (i = 1,2,3),

β_j is the order of the project ($j = 1,2,3$),

γ_k is the feedback condition ($k = 1,2,3$, where 1 = cognitive feedback, 2 = feedforward, and 3 = outcome feedback),

χ_l is the type of project ($l = 1,2,3$, where 1 = ideal, 2 = undersize, and 3 = fixedsize/bad estimate),

δ_m is the experimental participant ($m = 1,\ldots,45$),

$e_{ijk(l)m}$ is the experimental error term.

TABLE 7. DEVIATIONS FROM INITIAL ESTIMATES. Means and (Standard Deviations).

	N	Ideal	Undersize	Fixedsize
Cognitive Feedback	15	0.448 (1.723)	11.501 (4.43)	39.29 (1.854)
Feedforward	15	3.858 (1.794)	17.684 (2.058)	47.21 (5.605)
Outcome Feedback	15	10.014 (5.710)	25.753 (6.052)	57.027 (7.041)
Random Baseline	15	11.12 (6.12)	27.98 (7.23)	56.22 (9.12)

The analysis was conducted with the General Linear Models procedure (SAS, 1987). Table 8 contains the ANOVA results. The results show that the performance of subjects across the three different feedback conditions was significantly different ($F=345.89$, $p=0.0001$). The null hypothesis of no significant differences among feedback conditions is therefore rejected. In other words, the results indicate that the subjects' performance was influenced by the type of information provided to them.

TABLE 8. ANALYSIS OF VARIANCE. Dependent Variable: Deviation from Initial Estimates.

Source of Variance	S.S.	Degrees of freedom	F-Value	P	R-Square
Model	50769.00	57	136.54	0.0001	0.89
Type of Information	4530.01	2	345.89	0.0001	
Type of Task	44166.85	2	3372.37	0.0001	
Sequence	16.53	2	1.26	0.2887	
Order	3.16	2	0.24	0.7862	
Participant	2041.19	41	7.60	0.0001	
Group*Task	4.48	4	0.23	0.8126	
Group*Order	6.67	4	0.26	0.9036	
Within Groups	504.22	77			

Additionally, Table 8 shows that the performance within-subjects was significantly different depending on the type of project confronting them ($F=3372.37$, $p=0.0001$). The null hypothesis of no significant differences in performance depending on type of project presented is therefore also rejected.

The Tukey Test for Additivity indicated no presence of interaction effects between the sequence of projects ($p>0.2$), or the order in which projects were completed ($p>0.7$). Also, there were no interaction effects between the type of information provided and the type of project ($p>0.8$), nor the type of information provided and the order of project ($p>0.9$).

Table 9 summarizes tests comparing results from each of the feedback conditions with the random baseline with respect to deviations from initial estimates. The mean total deviation for subjects in the cognitive feedback and feedforward conditions was lower than the random baseline in

TABLE 9. COMPARISON BETWEEN EXPERIMENTAL GROUPS AND BASELINE. Dependent Variable: Deviation from Initial Estimates.

Comparison	Ideal Total deviation	Undersize Total deviation	Fixedsize Total deviation
Cognitive Feedback	r>cfb	r>cfb	r>cfb
Feedforward	r>ff	r>ff	r>ff
Outcome Feedback	n.s.	n.s.	n.s.

Notes: 1. cfb: cognitive feedback, ff: feedforward, n.s.: not significant, r: random baseline.

2. The comparisons represent one-tailed (directional) t-tests performed on the means. Thus, r>cfb indicates that the mean for that variable in the random baseline was higher than the mean in the cfb condition, at $p<0.05$. n.s. indicates that differences in the means, if any, were not significant at $p<0.05$.

all three projects. Subjects receiving only outcome feedback showed no significant performance differences from the random baseline in any of the three projects.

Table 10 summarizes staff productivity results. This information shows the actual productivity in tasks/man-day of the simulated staff as managed by the subject. Table 11 contains the ANOVA results for the staff productivity data. Again, there was a significant difference in performance between subjects ($F=106.88$, $p=0.0001$) as well as within-subjects ($F=109.59$, $p=0.0001$). The Tukey Test for Additivity indicated no presence of interaction effects between the sequence of projects ($p>0.9$), nor the order of the projects ($p>0.7$). Also, no interaction effects were present between the type of information provided and the type of project ($p>0.6$), nor the type of information provided and the order of projects ($p>0.4$).

TABLE 10. STAFF PRODUCTIVITY. Means and (Standard Deviations).

	N	Ideal	Undersize	Fixedsize
Cognitive Feedback	15	0.393 (0.051)	0.307 (0.047)	0.251 (0.051)
Feedforward	15	0.317 (0.049)	0.249 (0.051)	0.182 (0.049)
Outcome Feedback	15	0.249 (0.051)	0.177 (0.057)	0.112 (0.037)
Random Baseline	15	0.238 (0.060)	0.180 (0.071)	0.131 (0.032)

TABLE 11. ANALYSIS OF VARIANCE. Dependent Variable: Staff Productivity.

Source of Variance	S.S.	Degrees of freedom	F-Value	p	R-Square
Model	1.62	57	8.89	0.0001	0.86
Type of Information	0.43	2	106.88	0.0001	
Type of Task	0.44	2	109.59	0.0001	
Sequence	0.002	2	0.06	0.9443	
Order	0.006	2	0.09	0.7869	
Participant	0.71	41	1.37	0.0401	
Group*Task	0.005	4	0.66	0.6234	
Group*Order	0.007	4	0.98	0.4235	
Within Groups	0.16	77			

IV. CONCLUSIONS

A. SUMMARY OF RESULTS

The objective of this study was to investigate the effects of cognitive feedback, outcome feedback, and feedforward on decision makers in a dynamic decision environment such as software project management. Chapter II (section B.2) pointed out that past research has shown the dysfunctional effects of outcome feedback. These dysfunctional effects have led researchers to seek alternative means to improve decision quality. Chapter II (section C) discusses two alternatives to outcome feedback: cognitive feedback and feedforward. Both cognitive feedback and feedforward seek to assist the decision maker in formulating a "mental model" of the task which confronts him/her. Without this model, decision makers have exhibited poor performance in handling the delays and oscillations associated with complex dynamic systems. Additionally, Chapter II (section C.3) explains why one would expect cognitive feedback to improve decision makers' performance more than feedforward. The results of this study support these past findings. As the analysis of variance tests showed, there was a significant difference in subjects' performance depending on the type of feedback with which they were provided. Subjects in the cognitive feedback condition experienced less deviations from the initial project estimates than subjects in the feedforward or outcome feedback condition. Additionally, staffs managed by subjects receiving cognitive feedback showed greater productivity than staffs managed by subjects in the other feedback conditions. Also, tests comparing feedback groups with the random baseline showed that subjects in the cognitive feedback and feedforward conditions performed better than the random baseline in each of the three projects, whereas there was no significant performance difference between subjects receiving outcome feedback and the random baseline.

B. FEEDBACK AS A DECISION TOOL

The results of this experiment provide several implications for the design of project control systems, specifically those in support of software project managers. As Brehmer (1987) concluded from his DESSY experiment,

> These results show that system designers cannot rely upon the operators to develop good mental models f complex systems. This implies that we need to develop means that help the subjects develop such models, or possibly means that eliminate the need for predictive models. (p. 30)

Brehmer provides several suggestions for improving the quality of information systems. The most important one, with respect to this study, states the need to communicate information about the system in nonverbal form. As this study showed, presenting information in graphical form did, in fact, raise the performance level of subjects receiving that information.

C. LIMITING FACTORS TO GENERALIZABILITY[3]

Although a majority of the subjects in this experiment had some managerial experience, the question remains whether they had enough experience to play the game. In other words, is it reasonable to make a comparison between their performance and that of real life software managers?

Remus (1986) found, in a study to investigate the use of graduate students as surrogates for managers, that no significant differences existed between the students and managers in making production scheduling decisions. Although software project management is somewhat different from the task presented in Remus' experiment, it is similar enough to apply his findings and assume that software engineering graduate students are reasonable surrogates in this experimental investigation.

The next limiting factor to consider is the nature of the particular project environment. One should take caution against generalizing the results presented in Chapter III to all types of project situations. In this experiment, each of the three projects was developed in a familiar in-house environment i.e., what is typically described as an organic-type project environment (Boehm, 1981, pp. 78-82).

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[3]This section is based on an unpublished paper by Abdel-Hamid, Sengupta, and Ronan (1990) which describes a similar experiment using the SDM gaming interface.

Finally, it is difficult to claim external validity for laboratory-type studies. A review of the gaming literature by Remus (1978) does, however, indicate considerable similarity between decision making in games and managerial decision making per se. Since the project games in this experiment are a simulation of three real life software projects, there seems to be no reason why there should be any exception to Remus' general findings.

D. FUTURE RESEARCH

Based on the discussion in Section C above, one particular path for future research using the SDM gaming interface to investigate managerial decision making is evident. The above experiment could be replicated using real software project managers as the subjects. Although using graduate students as surrogates in research studies is useful, analyzing the behavior of experienced project managers could provide more significant and noteworthy results.

APPENDIX

EXPERIMENTAL INSTRUCTIONS PROVIDED TO SUBJECTS

A1 Written description given to subjects

Introduction

The exercise you are about to undertake is similar in many ways to flight simulators that pilots use to mimic flying an aircraft from takeoff at point A to landing at point B. Instead of flying the aircraft, though, this simulator mimics the life of a real software project from the start of the design phase until the end of testing. In this simulation, you will be more than an observer. In fact you will play a real role on the project: that of the project manager.

Specifically, your role will be to track the project's progress using a number of reports that will be produced for you at different intervals during the project. You will then make the project's staffing decisions based on the knowledge you gain from these reports. As the project manager, you can hire additional staff or decrease the staffing level as you deem necessary to complete the project. Your objective (like that of any software project manager) is to manage your resources wisely and efficiently while always aiming to finish the project within budget and on schedule (plus any safety factor period available.)

Projects

You will be given three projects to manage, all of them real projects conducted in a real organization. The organization is on the leading edge in its software engineering practices. For each project, you will be given a project profile containing the following initial information:

Estimated Project Size(in No. of tasks)
Estimated Schedule Duration(in No. of Work Days)
Estimated Project Cost(in No. of Man Days)
Maximum Tolerable Project Duration(in No. of Work Days).

Your Task

Your task is to use the reports generated by the project team at different points in the project to determine a desired staffing level for the remainder of the project. Your objective in setting the staffing level should be to decide on the best compromise between finishing on an acceptable schedule while avoiding an excessive cost overrun. Specifically, you should try to:

(a) complete the project on schedule,
(b) at the lowest possible cost, and
(c) in any case, complete it before the maximum tolerable completion date.

Your grade for the simulation will be based on an equal weighting of two factors:

(a) The percentage by which the project overshoots the original schedule. Thus, if the scheduled completion date for the project is 200 days, and your actual completion date is 240 days, you will be considered to have overshot the schedule by (240-200)/200 = 20%.

(b) The percentage by which the project overshoots the original cost estimate. If the original cost estimate is 2,000 man days and the actual cost of completion is 2,500 man days, you will be considered to have overshot the cost by (2,500-2,000)/2,000 = 25%.

The following are some important things to consider in making your decisions:

1. As the software project manager, you specify the desired staffing level. The actual staffing level may, of course, be different due to things you cannot control such as turnover and lengthy hiring delays.

2. Each project is initialized with a particular core team of full time equivalent personnel (FTE). This is to reflect that fact that most projects start out with a small core team of personnel. For example, project 2 may be initialized to an FTE of 1.5.

3. The hiring delay for new employees can take up to 6 weeks. Once new people are hired, the assimilation period for a newly hired employee is typically one month long. This is the time needed to train a new employee in the mechanics of the project and bring him/her up to speed. A new employee (i.e. one that is being trained) is only half as productive as an experienced employee.

4. The personnel turnover rate is 20% per year.

5. At different points in the project you will be given reported information on the status of the project. Two key pieces of information for this staffing task are: (1) The updated estimate of the total project cost in man days (this update can change to reflect the addition of new requirements and/or changes in the estimate of the team's overall productivity); and (2) Effort expenditures to date (also in man days). Subtracting the second from the first yields the "Remaining Effort in man days."

6. Let us say that at some point in the project the "Remaining Effort" is 1000 man days, the remaining time is 100 days and you have 7 full time equivalent employees working. You are, thus, in a position where you have to use your judgement to do one of the following:

   1. Stick with the current schedule. If so then you will need a staff size of 1000/100 = 10 full time employees.

   2. Stick with your staff size of 7. This means the schedule has to be pushed back. In this case the model will make the appropriate adjustment to the schedule for you. That is extend it to 1000/7 = 143 man days.

   3. Do a bit of both. That is increase the staff size a bit, say to 8, which will also mean that the schedule will be extended (appropriately by the model) to 1000/8 = 125 days.

<u>How to Play the Game</u>

1. First, take some time to practice and get familiar with the system.

   (a) Type DUMMY for running a dummy project.

   (b) Run the dummy project for 1 interval.

   (c) Go through all the options in the menu. Please be sure you understand all of them.

   (d) When you are done, hit <ESC>.

2. The real simulation starts now. You will be given three projects, one at a time. When you are done with one project, you can move on to the next, till you have completed all three projects.

3. For each project:

   (a) Insert the disk you are given, and enter a command from the A> prompt. The command for project 1 is PROJECT1, and so on.

   (b) The system will show you the size of the initial core team of senior designers (the full time equivalent number). It will then ask you for your initial desired staffing level.

   (c) Next it will run through the first simulation time period and show you the current reported statistics. Make your change to the full time equivalent staffing level on the documentation sheet provided after viewing the report.

   (d) Perform step (c) for as many intervals as necessary, till the project is complete. A project is considered complete when there are less than 40 days left for the project to be completed. That is,
   (New Estimate of Project Duration - Elapsed Time) < 40 days.
   Thus, if the New Estimate of Duration = 426 days, and the Elapsed Time = 400 days, the project is considered complete.

   (e) There is no need to turn in the documentation sheet after each interval of a project. However, A LAB ATTENDANT MUST VERIFY YOUR FINAL RESULTS at the completion of each project. Call a lab attendant as soon as you are done with a project.

   (f) Complete the appropriate questionnaire in your instruction booklet.

   (g) Move on to the next project.

<u>Rules of the Game</u>

* You will be required to provide the new desired staffing level for the project at the beginning of every two-month interval (consisting of 40 work days). The simulation will stop to show current reported statistics and accept a desired staffing level after each 40 day work period.

Annotate your desired staffing level on the documentation sheet and then enter it at the simulation prompt.

* YOU MUST WORK ALONE. You are not allowed to discuss this exercise with anyone other than a lab attendant. Also, please refrain from discussing this with any member in the other class until they have completed the exercise.

* Please follow the guidelines strictly. The system prompts, along with instructions in this booklet, will guide you at every stage.

* If you are in doubt about what to do next, ask for a lab attendant.

A1.1 Further instructions provided to cognitive feedback subjects

<u>How to use and Interpret the Plots</u>

Throughout the life of each project (starting with time elapsed = 40 days), you will have access to a series of plots providing information on the project. As the project progresses over time, the plots will be increasingly more meaningful in making your staffing decision. This and the next page explain how to interpret and use the plots in making your decisions.

Plot on Project Size
(refer to Chapter III, Figure 4)

The figure below provides information on whether any schedule or budget slippage is a result of: (1) unexpected increases in the project's size (e.g., due to changes in users' requirements), or (2) that we initially underestimated the effort required to complete the project (e.g. because we underestimated its complexity). In the first case, the Perceived Total Project Size (PJBSZ) will increase over time. In the second case, the Perceived Total Project Cost (JBSZMD) will increase over time.

Plot on Project Staffing vs Schedule
(refer to Chapter III, Figure 5)

The figure below provides feedback on the trade-off between minimizing schedule over-runs versus minimizing cost over-runs. When a project runs into trouble, a manager can choose to stick with the project's schedule (SCHCDT) by increasing the workforce level (FTEQWF). This always increases the cost of the project. On the other hand, a manager might desire to minimize his/her cost over-run, by avoiding an increase in the workforce level, and instead, increase the project's scheduled completion date. The indicated workforce level (WFINDC) is an estimate of the workforce needed to stay on schedule.

Plot on Workforce Mix
(refer to Chapter III, Figure 6)

A good feedback on why your costs may be higher than expected is to evaluate your staffing decision. In general, staffing decisions have the greatest impact on productivity. First, a larger workforce (FTEQWF) will, in most cases, be less productive because of the increases in communication and training overheads. Second, the workforce mix (i.e., percent of experienced vs new staff in the workforce) will also have an impact. The larger the percentage of experienced people in the workforce (FRWFEX), the more productive the workforce.

Plot on Workforce Productivity
(refer to Chapter III, Figure 7)

This figure provides information on the average productivity of the team. In general, your staffing decisions will affect productivity in two ways. The larger the workforce you assemble (FTEQWF), the lower the average productivity (ASSPRD). This is because in a larger workforce people "waste" more time communicating with team mates. This communication overhead is plotted above. The communication overhead (COMMOH) curve tells you the percentage of a person's time that is wasted (on average) in communication with others.

*** You are now ready to Start PROJECT 1 ***

A2 Information provided to subject for first project - order of projects varied depending on subject's group assignment (the order presented here is the same as the sequence given to subjects in Group 1: Ideal, Undersize, and then Fixedsize/bad estimate)

PROJECT 1

Management's Initial Project Estimates

Initial Estimate of Project Size:	1,067 Tasks
Initial Estimate of Project Cost:	3,721 Man Days
Initial Estimate of Project Duration:	413 Days
Maximum Tolerable Project Duration:	479 Days

A project is considered complete when there are less than 40 days left for the project to be completed. That is, (New Estimate of Project Duration - Elapsed Time) < 40 days.

Staffing Level Sought (in FTE)

Please enter your staffing decisions, i.e.,(In Full Time Equivalent) below:

Initial Estimate: ________________

Time elapsed - 40 days:________________

Time elapsed - 80 days:________________

Time elapsed - 120 days:________________

Time elapsed - 160 days:________________

Time elapsed - 200 days:________________

Time elapsed - 240 days:________________

Time elapsed - 280 days:________________

Time elapsed - 320 days:________________

Time elapsed - 360 days:________________

Time elapsed - 400 days:________________

Time elapsed - 440 days:________________

Time elapsed - 480 days:________________

Time elapsed - 520 days:________________

Time elapsed - 560 days:________________

Time elapsed - 600 days:________________

Time elapsed - 640 days:________________

*** WHEN YOU ARE DONE, PLEASE CALL FOR A LAB ATTENDANT ***

A3 Questions answered by all subjects after completion of first project

1. Describe (in words, numbers, equation, etc) what decision rule you followed in deciding on the staffing level in this project:

____

____

____

____

2. Please try to elaborate on the thinking process you went through in making your decisions in this project (use back of page if necessary):

____

____

____

3. How clear were the instructions regarding the task?

1	2	3	4	5	6	7	8	9
Not at all Clear								Very Clear

4. To what extent was the report on the progress of the project helpful in improving your own decision?

1	2	3	4	5	6	7	8	9
Not at all Helpful								Very Helpful

A3.1 Additional question asked of subjects in feedforward condition only

5. To what extent was the training provided before the experiment helpful in improving your own decision?

1	2	3	4	5	6	7	8	9
Not at all Helpful								Very Helpful

A3.2 Additional question asked of subjects in cognitive feedback condition only

6. To what extent was the graphical information provided on the progress of the project helpful in improving your own decision?

1	2	3	4	5	6	7	8	9
Not at all Helpful								Very Helpful

*** PLEASE MOVE ON TO PROJECT 2 ***

A4 Information provided to subject for second project - order of projects varied depending on subject's group assignment

Project 2

Management's Initial Project Estimates

Initial Estimate of Project Size:	397 Tasks
Initial Estimate of Project Cost:	1,460 Man Days
Initial Estimate of Project Duration:	380 Days
Maximum Tolerable Project Duration:	441 Days

A project is considered complete when there are less than 40 days left for the project to be completed. That is, (New Estimate of Project Duration - Elapsed Time) < 40 days.

Staffing Level Sought (in FTE)

Please enter your staffing decisions, i.e.,(In Full Time Equivalent) below:

Initial Estimate: ________________

Time elapsed - 40 days:________________

Time elapsed - 80 days:________________

Time elapsed - 120 days:________________

Time elapsed - 160 days:________________

Time elapsed - 200 days:________________

Time elapsed - 240 days:________________

Time elapsed - 280 days:________________

Time elapsed - 320 days:________________

Time elapsed - 360 days:________________

Time elapsed - 400 days:________________

Time elapsed - 440 days:________________

Time elapsed - 480 days:________________

Time elapsed - 520 days:________________

Time elapsed - 560 days:________________

Time elapsed - 600 days:________________

Time elapsed - 640 days:________________

*** WHEN YOU ARE DONE, PLEASE CALL FOR A LAB ATTENDANT ***

A5 Questions answered by subject after completion of second project were the same as those answered after the first project

*** PLEASE MOVE ON TO PROJECT 3 ***

A6 Information provided to subject for third project - order of projects varied depending on subject's group assignment

Project 3

Management's Initial Project Estimates

Initial Estimate of Project Size:	1,866 Tasks
Initial Estimate of Project Cost:	2,972 Man Days
Initial Estimate of Project Duration:	362 Days
Maximum Tolerable Project Duration:	420 Days

A project is considered complete when there are less than 40 days left for the project to be completed. That is, (New Estimate of Project Duration - Elapsed Time) < 40 days.

Staffing Level Sought (in FTE)

Please enter your staffing decisions, i.e.,(In Full Time Equivalent) below:

Initial Estimate: ________________

Time elapsed - 40 days:________________

Time elapsed - 80 days:________________

Time elapsed - 120 days:________________

Time elapsed - 160 days:________________

Time elapsed - 200 days:________________

Time elapsed - 240 days:________________

Time elapsed - 280 days:________________

Time elapsed - 320 days:________________

Time elapsed - 360 days:________________

Time elapsed - 400 days:________________

Time elapsed - 440 days:________________

Time elapsed - 480 days:________________

Time elapsed - 520 days:________________

Time elapsed - 560 days:________________

Time elapsed - 600 days:_______________

Time elapsed - 640 days:_______________

*** WHEN YOU ARE DONE, PLEASE CALL FOR A LAB ATTENDANT ***

A7 Questions answered by subject after completion of third project were the same as those answered after the first project

A8 Questions answered by cognitive feedback subjects after completion of entire experiment (subjects in the feedforward and outcome feedback answered only questions 1, 7, 8, 9, 10, 11, 12, 13 and 14.

1. In the projects that you just completed, did you

   (a) Use the project status report (Y/N)?_________

   (b) If you did, please describe how you used the information to make the staffing decision.

____

____

____

2. In the projects that you just completed, did you

   (a) Use the project staffing report (Y/N)?_________

   (b) If you did, please describe how you used the information to make the staffing decision.

____

____

____

3. In the projects that you just completed, did you

(a) Use the plot on project size (Y/N)?________

(b) If you did, please describe how you used the information to make the staffing decision.

____

____

____

4. In the projects that you just completed, did you

(a) Use the plot on staffing and schedule (Y/N)?______

(b) If you did, please describe how you used the information to make the staffing decision.

____

____

____

5. In the projects that you just completed, did you

(a) Use the plot on workforce mix (Y/N)?________

(b) If you did, please describe how you used the information to make the staffing decision.

____

____

____

6. In the projects that you just completed, did you

   (a) Use the plot on workforce productivity (Y/N)?______

   (b) If you did, please describe how you used the information to make the staffing decision.

____

____

____

7. Have you in the past, participated in project management (Y/N)? ___

8. If YES, to what extent was the task in this simulation similar to your previous experience?

1	2	3	4	5	6	7	8	9
Not at all Similar								Very Similar

9. How interesting was the task you just performed?

1	2	3	4	5	6	7	8	9
Not at all Interesting								Very Interesting

10. How serious were you in performing the task?

1	2	3	4	5	6	7	8	9
Not at all Serious								Very Serious

11. How clear were the instructions regarding the task, generally?

1	2	3	4	5	6	7	8	9
Not at all Clear								Very Clear

12. How easy was the system to use?

1	2	3	4	5	6	7	8	9
Not at all Easy								Very Easy

13. Please give us some information about yourself (in absolute confidence. At no time will your name appear in the results. The data will only be used in an aggregate statistical sense).

(a) Curriculum enrolled in: ____________________________

(b) Sex ______

(c) Age ______

(d) Full time work experience (in years) ______

(e) How long ago (in years) did you complete your undergraduate education? ______

(f) How familiar are you with computers, generally?

1	2	3	4	5	6	7	8	9
Not at all Familiar								Very Familiar

(g) How many hours (per week) do you use computers?

____

14. Your general comments regarding the simulation:

____

____

***** END OF SIMULATION *****

Thank you for your participation.

LIST OF REFERENCES

Abdel-Hamid, T.K., "The Dynamics of Software Project Staffing: A System Dynamics Based Simulation Approach," *IEEE Transactions on Software Engineering*, v. 15, no. 2, pp. 109-119, February 1989.

Abdel-Hamid, T.K. and Madnick, S.E., "Lessons Learned from Modeling the Dynamics of Software Development," *Communications of the ACM*, v. 32, no. 12, pp. 1426-1455, December 1989.

Abdel-Hamid, T.K., Sengupta, K., and Ronan, D., "Software Project Control: An Experimental Investigation of Judgment Under Fallible Information," paper submitted for publication, August 1990.

Anthoney, R.N., and Dearden, J., *Management Control Systems*, Chicago, IL: Richard D. Irwin, Inc., 1980.

Balzer, W.K., Doherty, M.E., and O'Connor, R., "Effects of Cognitive Feedback on Performance," *Psychological Bulletin*, v. 106, pp. 410-433, 1989.

Barlow, D.H., and Hersen, M., *Single Case Experimental Designs: Strategies for Studying Behavior Change*, New York, NY: Permagon Press, 1984.

Bjorkman, M., "Feedforward and Feedback as Determiners of Knowledge and Policy: Notes on a Neglected Issue," *Scandinavian Journal of Psychology*, v. 13, pp. 152-158, 1972.

Boehm, B.W., *Software Engineering Economics*, Englewood Cliffs, NJ: Prentice-Hall, Inc., 1981.

Brehmer, B., "Systems Design and the Psychology of Complex Systems," in J. Rasmussen and P. Zunde (Eds.), *Empirical Foundations of Information and Software Science III*, pp. 21-32, New York, NY: Plenum, 1987.

Brehmer, B., and Allard, R., *Dynamic Decision Making: A General Paradigm and Some Experimental Results*, Manuscript, Uppsala, NY: Uppsala University, Department of Psychology, 1985.

Conant, R.C., and Ashby, W.R., "Every Good Regulator of a System Must be a Model of that System," *International Journal of System Science*, v. 1, pp. 89-97, 1970.

Doherty, M.E. and Balzer, W.K., "Cognitive Feedback," in B.Brehmer and C.R.B. Joyce (Eds.), *Human Judgement, The SJT View*, pp. 163-197, Amsterdam: Elsevier Science Publishers, 1988.

Forrester, J.W, *Industrial Dynamics*, Cambridge, MA: The MIT Press, 1961.

Hogarth, R.M., "Beyond Discrete Biases: Functional and Dysfunctional Aspects of Judgmental Heuristics," *Psychological Bulletin*, v. 90, no. 2, pp. 197-217, 1981.

Jacoby, J., Mazursky, D., Troutman, T., and Kuss, A., "When Feedback is Ignored: Disutility of Outcome Feedback," *Journal of Applied Psychology*, v. 69, pp. 531-545, 1984.

Kirk, R.E., *Experimental Design: Procedures for the Behavioral Sciences*, Monterey, CA: Brooks/Cole, 1982.

Kleinmuntz, D.N., "Cognitive Heuristics and Feedback in a Dynamic Decision Environment," *Management Science*, v. 31, pp. 680-702, 1985.

Kleinmuntz, D.N., and Thomas, J.B., "The Value of Action and Inference in Dynamic Decision Making," *Organizational Behavior and Human Decision Processes*, v. 39, pp. 341-364, 1987.

Morris, N.M., and Rouse, W.B., "On Looking Into the Black Box: Prospects and Limits in the Search for Mental Models," *Psychological Bulletin*, v. 100, no. 3, pp. 349-363, 1986.

Powers, W.T., "Feedback: Beyond Behaviorism," *Science*, v. 179, 1973.

Remus, W.E., "Testing Bowman's Managerial Coefficient Theory Using a Competitive Gaming Environment," *Management Science*, v. 24, no. 8, pp. 827-835, April 1978.

Remus, W.E., "Graduate Students as Surrogates for Managers in Experiments on Business Decision Making," *Journal of Business Research*, v. 14, pp. 19-25, 1986.

SAS/STAT, *Guide for Personal Computers*, Version 6, Cary, NC: SAS, 1987.

Schlender, B.R., "How to Break the Software Logjam," *Fortune*, pp. 100-112, 25 September 1989.

Sterman, J.D., "Misperceptions of Feedback in Dynamic Decision Making," *Organizational Behavior and Human Decision Processes*, v. 43, pp. 301-335, 1989.

Sterman, J.D., "Modeling Managerial Behavior: Misperceptions of Feedback in a Dynamic Decision Making Experiment," *Management Science*, v. 35, no. 3, pp. 321-339, March 1989.

Wagenaar, W.A., and Timmers, H., "The Pond-and-Duckweed Problem: Three Experiments on the Misperceptions of Exponential Growth," *Acta Psychologica*, v. 43, pp. 239-251, 1979.

Winer, B.J., *Statistical Principles in Experimental Design*, New York, NY: Mcgraw-Hill, 1971.

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